REPORT TO CONGRESS

THE ADVANCED ACCELERATOR APPLICATIONS PROGRAM PLAN

UNITED STATES DEPARTMENT OF ENERGY

PREPARED BY THE

OFFICE OF NUCLEAR ENERGY, SCIENCE AND TECHNOLOGY
&
COORDINATED WITH THE
NATIONAL NUCLEAR SECURITY ADMINISTRATION

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Executive Summary

The Conference Report to the Energy and Water Appropriations Act for 2001 directed the Department of Energy to establish a new program for advanced accelerator applications, and prepare a program plan for managing and executing the new program. This document fulfills that requirement.

The United States has a unique opportunity to embark upon a comprehensive approach to address key issues related to nuclear energy, science and technology. The Advanced Accelerator Applications (AAA) program can develop and demonstrate technologies applicable to nuclear waste solutions, and create a unique 21st Century nuclear engineering test facility. The use of high-energy accelerators coupled with sub-critical multipliers has been discussed internationally for many years as a way to transmute the components of used nuclear fuel into lower quantity, less toxic materials. France, Japan, Italy, and Russia have performed experiments and developed plans to investigate this method of waste management.

> ***Transmutation***
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> *Transmutation is the transformation of one material into another. It can occur naturally, through radioactive decay (e.g., the natural decay of Carbon-14 into nitrogen is commonly used to date artifacts). Transmutation can also be driven by a nuclear reactor or particle beam accelerator or both in combination. Transmutation can convert nuclear waste materials that are hazardous for millions of years into materials that are hazardous for centuries or even decades.*

The United States has come late to this possibility, only beginning a significant research effort in the last few years, most particularly through its Accelerator Transmutation of Waste (ATW) Program, established in FY 2000. However, for several years, the U.S. has been making investments in high energy accelerators, spent fuel treatment, and transmutation research that make it possible for the nation to launch a new, aggressive effort to explore this new area of technology. More significantly, the U. S. has come to realize that its aging nuclear infrastructure will become inadequate to support meaningful research and development in any advanced nuclear areas such as transmutation, advanced reactors, space power, *etc*.

This *AAA Program Plan* describes a potential ten-year activity of advanced nuclear technology research**,** and design and construction of an Accelerator–Driven Test Facility (ADTF). Such a facility would explore technologies for demonstration of accelerator-based transmutation of waste while providing a back-up capability for production of tritium if needed for national security purposes. In addition the facility would have a capability to augment or backup Department sources for vital accelerator-produced medical and industrial isotopes. The Plan provides detailed information on activities that could be conducted in the first two years, when conceptual design of the ADTF and related development activities would provide firm cost and schedule data to inform a program decision on whether to proceed with a full 10-year program. Finally, the Plan describes the closely integrated team of national laboratories, industry, and universities already in place to support AAA Program activities.

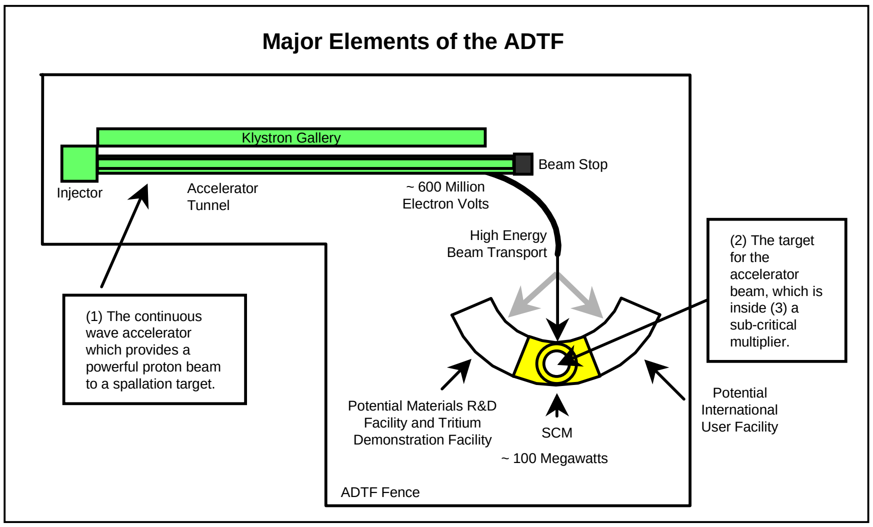
The mission of the Advanced Accelerator Applications (AAA) Program is to establish a national nuclear technology research capability, a nuclear engineering test bed that can carry out effective transmutation and advanced reactor research and development effort. The program would also provide a backup capability for tritium production scaleable to national security needs, and provide accelerator-produced isotopes if required.

The program must address the following objectives:

1. *Demonstrate the practical performance of an accelerator-driven sub-critical multiplier;*
2. *Demonstrate the viability of transmutation for waste and spent fuel management;*
3. *Enhance the Nation's nuclear science and technology education infrastructure;*
4. *Provide a more robust backup tritium production capability for national security.*

The Accelerator-Driven Test Facility (ADTF) would be the key facility for the AAA program. Existing facilities can support partial completion of the program objectives, but a new, dedicated facility is required for fully reaching the goals of the AAA Program. There exists no facility in the world capable of demonstrating the safe and efficient coupling of an accelerator, spallation target, and sub-critical multiplier. The ADTF would be designed to perform specific experiments related to the demonstration of waste transmutation, and would have the flexibility to carry out a broad range of experiments for a wide range of advanced nuclear technologies.

The ADTF would be comprised of two components: an advanced high energy accelerator that would provide protons to experimental facilities, and a sub-critical multiplier that includes a spallation target. In addition a series of flexible experimental user stations would be provided to support advanced nuclear research, materials science, and experimental physics.



In addition to its capabilities for transmutation research, the ADTF would be capable of acting as a user facility, with a unique capability for nuclear engineering studies based on the world's most intense source of spallation neutrons and intermediate energy protons, and a multiplying nuclear assembly. The ADTF would have a unique radiation damage investigative capability, and a capability to examine changes in properties (tensile strength, stress and fatigue, corrosion resistance, etc.) of materials proposed for future fission and fusion reactors. Other possibilities would include measurement of reactions on short-lived target nuclei, yielding data important to weapons science and astrophysics.

Finally, the ADTF would have the flexibility to divert a portion of the proton beam in the 70-100 MeV range for a target irradiation facility to generate accelerator-produced isotopes for medical and industrial purposes. Such a facility would augment other Department isotope production facilities, providing a reliable backup capability and replacement capability on an as-needed basis.

In the first two years the Department would lay the groundwork for the AAA Program and define how the program would achieve its objectives. By the end of the second year, the AAA program would develop the scope, cost, and schedule data necessary to fully define the 10-year program and to support a management decision regarding whether to proceed with the program. To accomplish this goal would require first year program funding of about $70 million; and a range of $110 to $130 million for the second year.

The Department estimates that in the range of $140 to $170 million would be required in the third year of a full AAA Program to complete required activities. The approximate cost for the entire 10-year AAA Program is estimated at $2.3 billion in FY 2001 dollars, including the construction of an ADTF and all relevant program research.

The AAA Program is a National program for development of nuclear technology through advanced accelerator applications. The AAA Program Office, established in the Office of Nuclear Energy, Science and Technology, will lead the program, partnering with the Office of Defense Programs, with expert support from the Office of Science, the Office of Defense Nuclear Non-Proliferation, and National Security. The technical team includes Los Alamos National Laboratory and Argonne National Laboratory as the lead laboratories, with support from the Savannah River Site, Oak Ridge National Laboratory, Livermore National Laboratory, Brookhaven National Laboratory, Thomas Jefferson National Laboratory, Sandia National Laboratory, and others. Industrial partners include Burns & Roe, Inc. teamed with General Atomics, for the existing scope of work under contract (the accelerator and the balance of plant), and the Westinghouse Savannah River Corporation. New work scope for a sub-critical multiplier or related technologies would be contracted competitively.

Assuming adequate resources and further project planning, the AAA program is designed to develop and demonstrate advanced technologies directly applicable to solution paths for key domestic and international nuclear issues. Over a 10 year period, an AAA Program would address the following objectives:

1. Construction of a first-of-a-kind nuclear engineering research facility with user access to advance nuclear science for energy and national security missions;
2. Demonstration of new, technically viable methods to help solve the long-term challenge of used nuclear fuel;
3. Launching a strengthened academic nuclear infrastructure that educates new scientists and engineers for both energy and national security; and
4. Development of a robust backup technology for tritium production for national security.

The AAA Program has defined a realistic, but aggressive, plan to be completed following an initial two-year definition period. With the completion of such a period, the Department would obtain sufficient information to support a management decision as to whether to proceed with an eight year activity to develop, design, and construct an ADTF. A broad national team of program, laboratory, and industry participants would execute the planning and implementation of such a program, with independent oversight. The AAA Program, if implemented as planned, would greatly enhance the currently declining national nuclear technology infrastructure and create technology needed to enhance the potential of the Nation's energy resources.

Note that this AAA Program Plan has been prepared and written so that it is responsive to the direction in Conference Report 106-907, for the FY 2001 Energy and Water Appropriations Act. It makes no attempt to establish AAA as a priority among the several technologies that might benefit the future of nuclear power. Should the Department proceed with a program to develop AAA, the actual activities and schedule would depend on future funding.

I. Introduction

The Fiscal Year 2001 Conference Report to the Energy and Water Appropriations Act directed the Department to "establish a new program for advanced accelerator applications" (and) "…prepare a program plan for managing and executing a new program for advanced accelerator applications using the extensive expertise of the Office of Science and the Office of Defense Programs in accelerator research, design, and applications, and the expertise of the Office of Nuclear Energy, Science, and Technology in transmutation of nuclear waste". The Department has established the program, and provides this program plan, as directed by Congress. The AAA was formed by merging the Accelerator Production of Tritium (APT), and Accelerator Transmutation of Waste (ATW) programs to maximize the objectives of the Office of Nuclear Energy and the National Nuclear Security Administration (NNSA). It will provide long-term accelerator-based programs for nuclear research and waste treatment, and a tritium production backup capability. The combined program provides more capability and potential benefits than the two separate programs it subsumed. The use of high-energy accelerators coupled with sub-critical multipliers has been discussed internationally for many years as a way to transmute the components of used nuclear fuel into lower quantity, less toxic materials. Countries such as France, Japan, Italy, and Russia have performed experiments and developed plans to investigate this method of waste management.

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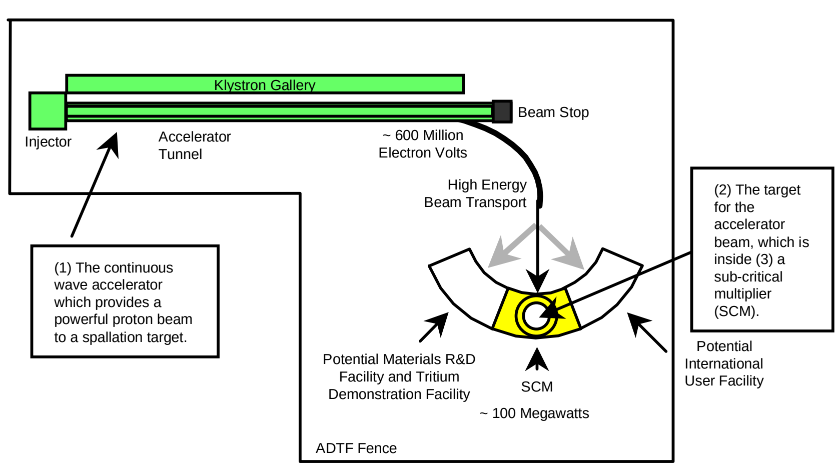
Major Elements of the ADTF



The United States government has come late to this possibility, only beginning a significant research effort in the last few years, most particularly through its Accelerator Transmutation of Waste (ATW) Program, established in FY 2000. However, for several years, the U.S. has been making investments in high energy accelerators, spent fuel treatment, and transmutation research that make it possible for the nation to launch a new, aggressive effort to explore this new area of technology. More significantly, the U. S has come to realize that its aging nuclear infrastructure will become inadequate to support meaningful research and development in any advanced areas such as transmutation, advanced reactors, space power, *etc*.

Vigorous efforts to rebuild the national nuclear science and technology infrastructure, if implemented correctly, will enable the DOE to perform a wide array of research and development, and demonstration missions for both civilian and national security applications. Recognition of this possibility resulted in the proposed Advanced Accelerator Applications (AAA) Program, and identification of the need for a new Accelerator Driven Test Facility (ADTF). Under the proposed program, exploring ATW would be one of many missions that could be accomplished. The AAA Program presents an opportunity to contribute toward the rebuilding of the national nuclear infrastructure by constructing a new ADTF. ATW would be one of a number of missions that could be carried out using such a facility.

This document, *the AAA Program Plan*, provides information to Congress on the cost, schedule and potential benefits of constructing an Accelerator-Driven Test Facility and conducting scientific and engineering research for the development of a potentially economical and environmentally acceptable accelerator transmutation of waste process. The Department has made no decision to proceed with such a project pending an energy policy review, Departmental readiness reviews, and resource availability; thus, this information is conceptual and provided for discussion purposes only.

The Department of Energy is exploring this new technology as a potential means of augmenting its aging nuclear science and technology infrastructure. Recently the Nuclear Energy Research Advisory Committee (NERAC) informed the Department that it had concluded that the U.S. nuclear research infrastructure – following a decade of neglect and decline – could no longer support even a modest expansion in the Federal nuclear research and development program. The Department launched a Nuclear Infrastructure Programmatic Environmental Impact Statement (NI-PEIS) to develop a response to its infrastructure needs. One decision reached was to proceed with conceptual design of an Accelerator-Driven Test Facility.

Background: Accelerator Production of Tritium And Accelerator Transmutation of Waste

The Accelerator Production of Tritium (APT) Program was established in 1995, with the Commercial Light Water Reactor (CLWR) program, as part of a dual-path strategy for development of a new tritium production technology for the nation. From 1995 through 2001, Defense Programs has invested more than $600 million in design and development of an accelerator to produce tritium, including a full-scale prototype of the front-end of the accelerator. In December 1998 the Department chose the CLWR as the primary technology for tritium production, assigning the APT a role as a backup technology. The AAA Program affords NNSA the opportunity to establish a backup technology, if required, that would be more robust than originally envisioned.

The Accelerator Transmutation of Waste (ATW) program was funded by Congress in FY 2000 to investigate the feasibility of accelerator-driven systems to transmute long-lived toxic components of used nuclear fuel.

This *AAA Program Plan* describes a potential ten-year activity of advanced nuclear technology research and design and construction of an Accelerator–Driven Test Facility (ADTF). Such a facility would explore technologies for demonstration of accelerator-based transmutation of waste while providing a back-up capability for production of tritium if needed for national security purposes. (It is important to note that these capabilities would not obviate the need for a nuclear waste repository). In addition the facility would have a capability to augment or backup Department sources for vital accelerator-produced medical and industrial isotopes. The Plan provides detailed information on activities that could be conducted in the first two years, when conceptual design of the ADTF and related development activities would provide credible cost and schedule data to inform a program decision on whether to proceed with a full 10-year program. Finally, the Plan describes the closely integrated team of national laboratories, industry, and universities already in place to support AAA Program activities.

The Department's Office of Nuclear Energy, Science and Technology, with its expertise in nuclear technologies essential to the program, has taken the lead in managing this program and is partnering with the National Nuclear Security Administration and coordinate with other DOE elements to assure success. The Director of the AAA Program Office has been designated by the Office of Nuclear Energy, and the Deputy Director by the Director, Office of Defense Programs. Defense Programs supports the AAA program using experienced technical and project management staff from its Accelerator Production of Tritium (APT) program, merging much of its APT laboratory and contractor activities into the AAA program. NNSA/DP could remain responsible for ensuring that the tritium backup capabilities are an integral part of the ADTF design, at least until the CLWR, the primary tritium production technology, is in full production. At that time the NNSA role would be reconsidered. The Office of Defense Nuclear Nonproliferation would support this activity by providing independent nonproliferation assessments. The Office of Science provides its expertise to support efforts related to accelerators, neutron targets, and user facility creation and operation.

II. Mission and Objectives of the AAA Program

Mission

If a decision is made to carry out the full 10-year program, the mission of the Advanced Accelerator Applications (AAA) Program would be to establish a national nuclear technology research capability, a nuclear engineering test bed that can carry out effective transmutation and advanced reactor research and development effort. The program would also demonstrate a backup capability for tritium production scaleable to national security needs, and provide accelerator-produced isotopes if required.

Program Objectives

If a decision is made to move forward with the full 10-year program, the following objectives would define program success:

1. *The AAA program would provide a proof-of-principle demonstration of an accelerator-driven sub-critical multiplier.*

The AAA Program would demonstrate coupling of a high power accelerator, with a sub-critical multiplier into an integrated operating system known as the Accelerator-Driven Test Facility (ADTF). Proof-of-Performance testing in the ADTF would demonstrate:

- A user facility, or nuclear engineering test bed, that allows testing of advanced nuclear materials and fuels, materials science research, experimental physics, and conventional nuclear engineering applications.
- Safe operation of a complete system coupling an accelerator, sub-critical multiplier, target, fuel, and balance of plant systems, both in normal and abnormal conditions.
- Technology options for the transmutation of spent nuclear fuel and waste through a series of integrated experiments aimed at demonstrating the performance and practicality of the proposed technologies.
- The capability to demonstrate tritium production and, through upgrades or additions, to produce tritium for national security purposes, or other accelerator-produced radioisotopes if required.

2. *The AAA program would conduct research on the viability of transmutation for waste and spent fuel management.*

Transmutation of spent fuel and nuclear waste, if successful, could significantly reduce long-term radiotoxicity by destroying actinides that are serious environmental and proliferation concerns. A key question then, is whether transmutation can provide a practical waste management technology option under realistic conditions. To answer this requires research and development in two areas: transmutation and systems integration.

Transmutation research and development and system integration studies are based on a structured framework that defines performance requirements, considers all elements of integrated transmutation systems and is focused on identifying and prioritizing those activities that lead to proof-of-performance testing and ultimate demonstration of waste transmutation. The objective of transmutation R&D would be to:

- Explore significant reduction in the amount of long-lived waste that requires long-term disposal (this technology does not replace the need for a repository);
- Explore material reductions by transmutation for impact on the environment and proliferation risk reduction;
- Explore waste generation in the processes of transmutation, material separations, and materials recycle and ensure that waste forms can be optimized for recycle.

These objectives would be pursued by selection and development of advanced technologies to separate used nuclear fuel for transmutation, and development of fuel forms that do not produce plutonium during irradiation.

The objective of systems integration studies would be to:

- Develop fuel cycle analyses of multi-tier approaches for integrating multiplier, fuel processing and fabrication, accelerator, and repository facilities;
- Develop materials flow diagrams that integrate separation efficiencies, transmutation conversion rates, and repository requirements;
- Evaluate these approaches for safety performance, environmental impacts, and proliferation risks; and
- Conduct in-depth economic analyses on approaches to transmute wastes and generate electricity.

3. The AAA program would enhance the Nation's nuclear science and technology education infrastructure.

The infrastructure needed to support essential nuclear technology in the 21st century is deteriorating. Facilities are aging, and the nuclear disciplines vital to our technology base (such as nuclear engineering, nuclear chemistry, physics, materials research, etc.) are in decline. A primary goal of the AAA Program from the outset could be to establish aggressive programs to engage universities and laboratories nationwide in nuclear research and encourage advanced degrees in the nuclear sciences. The new Office of Advanced Accelerator Applications has a pilot program in FY 2001 that will provide funds for advanced degrees at U.S. universities, which would be expanded in subsequent years. The Department has also established an agreement with the University of Nevada, Las Vegas for initiation of a $3 million program for participation in research, facilities, and encouragement of advanced degrees. Participation in the AAA program and, ultimately the availability of the ADTF would provide a focus to the programs and help to energize the nuclear community, and reverse the decline.

Reactors & Sub-Critical Multipliers

*Nuclear reactors are designed to operate by a continuous sustained nuclear reaction. In this **'**critical**'** mode, sufficient excess neutrons are produced from each fission to initiate subsequent fission and maintain the reaction**;** unless controlled, the reaction will continue as long as there is fuel.*

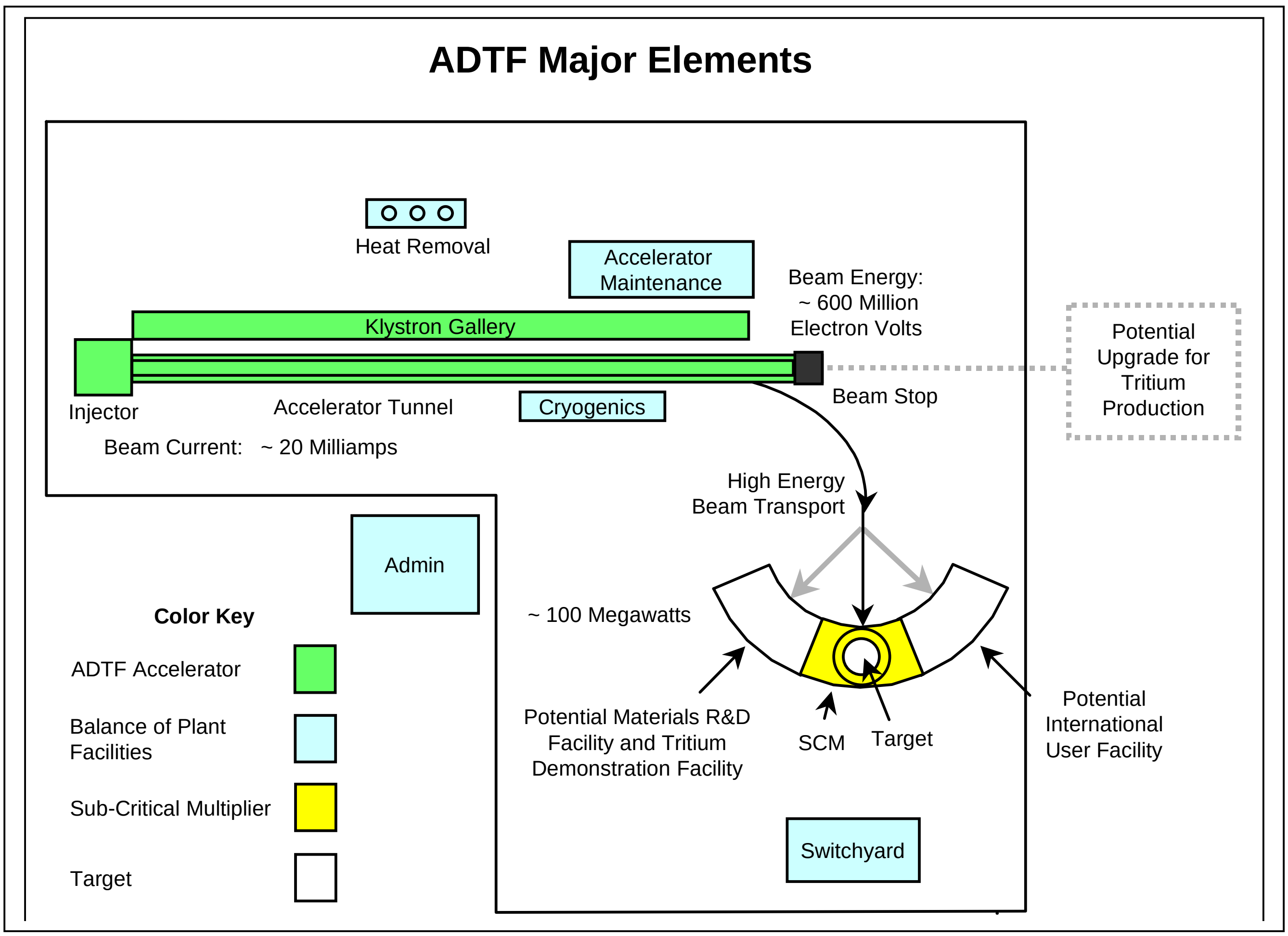
Sub-critical multipliers such as that planned for the ADTF do not maintain a self-sustaining reaction – and thus are not reactors in the classical sense. An outside source, such as an accelerator coupled with a spallation source, must provide additional neutrons to initiate and sustain nuclear reactions. When the accelerator is turned off, the nuclear reaction is quickly terminated. This enables a new approach to controlling and operating nuclear systems.

4. The AAA Program would provide a more robust backup tritium production capability for national security.

The AAA Program would provide nuclear technology for national security first through meeting its objectives in waste transmutation and infrastructure reinvigoration, which impact national defense as much as the civilian nuclear arena. Secondly, where the APT accelerator design would have been shelved in 2002 after the validity of the backup technology was demonstrated, under the AAA Program it would be adapted and built as an ADTF accelerator, upgradeable to produce tritium in the future if needed. The APT accelerator was planned as a 1,030 Million electron Volt (MeV) machine; the ADTF accelerator would be approximately 600 MeV. In addition, development needed for the ADTF may identify more effective options for tritium production.

III. Development of an Accelerator-Driven Test Facility

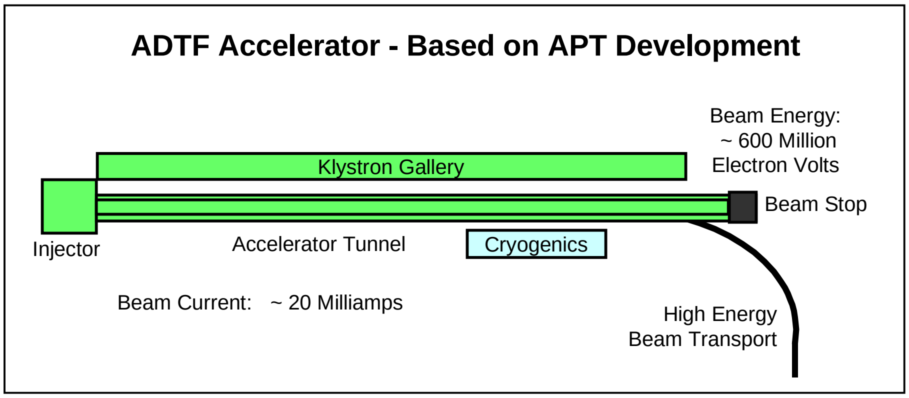
The Accelerator-Driven Test Facility (ADTF) would be the key facility for the AAA program. Existing facilities can support partial completion of the program objectives, but a new, dedicated facility would be required for fully reaching the goals of the AAA Program. There exists no



facility in the world capable of demonstrating the safe and efficient coupling of an accelerator, spallation target, and sub-critical multiplier. The ADTF would be designed to be able to perform specific experiments related to the demonstration of waste transmutation, and would also have the flexibility to carry out a wide range of experiments in support of a wide range of advanced nuclear technologies.

The ADTF would be comprised of two components: an advanced high energy accelerator that would provide protons to experimental facilities, and a sub-critical multiplier that would include a spallation target. In addition a series of flexible experimental user stations would be provided to support advanced nuclear research, materials science, and experimental physics.

Accelerator

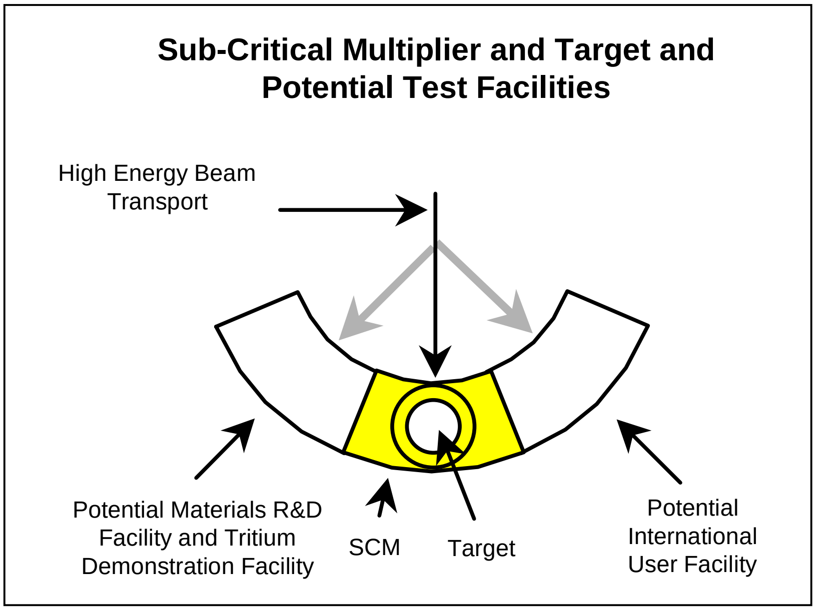


The design of the ADTF accelerator would be based on technologies and designs developed during the APT program. It would be designed to generate a 10 to 20 milliAmpere (mA) continuous proton beam with an energy of approximately 600 MeV. The accelerator would also be designed to permit upgrade to higher performance if required for full-scale tritium production and/or as a research tool for accelerator development. In particular, it would be designed to achieve the beam availability and reliability needed for accelerator-driven system applications. Most accelerators use a pulsed beam, and need only be available for the short duration generally required by basic science experiments. Operating an accelerator to support a sub-critical multiplier will require a beam with higher availability and much greater reliability.

Sub-Critical Multiplier

The sub-critical multiplier (SCM) would consist of a powerful spallation target immersed within a high power sub-critical multiplying array of nuclear fuel elements. It would be a first of a kind facility demonstrating that an accelerator, a spallation target, and a sub-critical multiplier can be coupled and operated safely and efficiently with high reliability. Given the January 19, 2001 decision by former Secretary of Energy Richardson to permanently deactivate the Fast Flux Test Facility, which provided a unique capability, the proposed new facility could provide that capability and be an asset to nuclear technology development.

The SCM would have a thermal power of up to 100 MWth, reached through a series of phased efforts to demonstrate operational performance. The facility would ultimately be designed to simulate the environments of advanced nuclear energy plants, including the use of candidate fuel forms and coolant technologies. However, in order to reduce initial technical risk, existing technologies would be used whenever feasible. The transmutation environment in the sub-critical multiplier would be scaled to achieve credible testing conditions, thereby reducing the need for further testing. As the premier international testing ground for transmutation technologies it would demonstrate the performances of fuels and materials used in transmutation technologies in prototypical spectra and temperatures to help resolve important issues related to waste transmutation technologies.



The SCM would be designed to accommodate prototypical irradiation environments for other advanced materials and nuclear fuels; for example, it might contain several different coolants and operate at high temperatures and neutron fluxes. The SCM would be designed to accommodate a wide range of conditions and large volumes, enabling the testing of materials and fuels under normal and severe conditions, to support advanced missions such as the development of space reactors, new proliferation resistant fuels, high burn-up fuels; and high temperature materials. The SCM could also be used to irradiate sufficient quantities of nuclear fuel dedicated to waste transmutation to high levels of burn-up for proof-of-performance purposes. Finally, separated materials would be reconstituted into new fuel elements to be reintroduced in the SCM thus demonstrating the full range of the transmutation process. In addition the safety envelope of the ADTF would be defined to accommodate severe transient testing conditions, including safety transients that test dynamic behavior of fuel.

<u>Other capabilities</u>

In addition to its capabilities for transmutation research, the ADTF would be capable of acting as a user facility, with a unique capability for nuclear engineering studies based on the world's most intense source of spallation neutrons and intermediate energy protons, and a multiplying nuclear assembly. The ADTF would have a unique radiation damage investigative capability, and a capability to examine changes in properties (tensile strength, stress and fatigue, corrosion resistance, etc.) of materials proposed for future fission and fusion reactors. Other possibilities would include measurement of reactions on short-lived target nuclei, yielding data important to weapons science and astrophysics.

Finally, the ADTF would have the flexibility to divert the proton beam to a target irradiation facility to generate accelerator-produced isotopes for medical and industrial purposes. Such a facility would augment other Department isotope production facilities, providing a reliable backup capability and replacement capability on an as-needed basis.

IV. Major Technology Challenges

The AAA program would need to address complex science and technology issues both in the design and, if constructed, the operation of the ADTF and in the demonstration of the value of transmutation as a waste management strategy. Resolution of these issues would result in development of new technologies that would contribute to the foundation for advanced reactor technologies, and also provide unique, invaluable training opportunities for U.S. students.

<u>ADTF</u>

The challenges in the development of the ADTF would lie in the safe, controlled coupling of an accelerator to a sub-critical multiplier through a spallation target. The accelerator technology is well known today, and the major components are, for the most part, commercially available.

Spallation Target

The spallation target proposed for the ADTF system would be in the power range of 2-6 megawatts. The largest target designs developed to date are in the one megawatt range; but both the Spallation Neutron Source and the APT have designed components and performed research aimed at higher target power (up to 4 MW and 100 MW respectively). The major engineering challenges in developing the ADTF high power target would be***:*** 1) target heat removal; 2) the design and useful life of the 'windows' through which the beam leaves the accelerator to impact on the target; 3) target materials and lifetime; 4) acceptable target waste products and 5) insertion of the target into the sub-critical multiplier. A number of target materials are under study, including tungsten, lead, lead/bismuth, and uranium. Each type has its own unique properties. However, a significant amount of target and window research and testing would have to be performed before a final choice is made for the ADTF.

Coupled System Design and Operation

A complete coupled accelerator, spallation target and sub-critical multiplier system has yet to be built, tested and operated. The major challenges would be design of a facility that permits insertion of the target into the multiplier with adequate control, shielding and system reliability. System control and safe operation would demand an understanding of integration of the coupled accelerator/target/multiplier system. (It has not been determined whether the proposed ADTF would fall under regulation of the Defense Nuclear Facility Safety Board (DNFSB) or the Nuclear Regulatory Commission (NRC). The ADTF would be designed to meet appropriate regulatory requirements.

<u>Transmutation</u>

The objectives of the transmutation research portion of the AAA program would include: 1) demonstration that there is a significant reduction in the amount of long-lived waste that requires long term disposal; 2) demonstration that these reductions have a material impact on the environmental and proliferation risk; 3) demonstration that minimal additional waste is generated in the processes of transmutation, material separation and recycle; and 4) demonstration of waste forms from these processes that provide benefit for geologic disposal**.** Resolution of these issues requires research into new fuels and separations technologies in conjunction with studies of transmutation strategies.

Transmutation Strategies

Transmutation research would focus on the development of fuel cycle strategies that seek to identify the relative merits and optimum combinations of accelerator-driven systems and reactor options for spent fuel management in a safe and environmentally responsible way. Studies will address the performance capabilities of both reactor and accelerator-based transmutation systems, set performance requirements for transmutation and separations efficiency, and define acceptable waste form characteristics. Ultimately acceptable performance would be demonstrated by ensuring that waste streams are more environmentally benign than the initial spent fuel and demonstrating that the resulting complete system meets U.S. non-proliferation goals.

Non-Fertile Fuels

Since an accelerator-driven system for transmutation is predicated upon the fact that rapid destruction of fissile material is required, one of the objectives of transmutation technology research would be the development and demonstration of non-fertile fuels that do not contain uranium 238 and therefore do not produce plutonium. While basic reactor and materials principles are understood, very little experience with the properties, fabrication, and performance of these unique fuels would be available. Key to the development of non-fertile fuels is a safe environment in which to test such fuels. Initial testing would be performed in conventional fuels test reactors, but ultimately a reactor with prototypical spectrum, coolant and thermal conditions would be required. The ADTF would provide such a prototypical environment The ADTF would not only test these new fuels, but could evolve over time to an all non-fertile fuel system, which would be equivalent to a small-scale operating prototype waste transmutation system.

Separations

Efficient transmutation of transuranic elements and key long-lived fission products requires a separation of these constituents from spent nuclear fuel. That separation would have to be done economically, with minimum waste generation, and without increasing the risk of proliferation of weapons technologies. Separations processes would have to be applied to existing commercial reactor spent fuel as well as to the non-fertile fuels required for the transmutation process. Because of their different uses, these fuels are quite dissimilar in character; commercial fuel is present in significant tonnage, while the transmuter fuel; which would not contain uranium, would be much more limited in quantity. The compositions and nuclear characteristics of these fuels are also quite different. A chemical separation technology that may be ideal for one fuel type is likely not to be the optimum for the other fuel type. It would therefore be necessary to develop appropriate separations technologies and demonstrate processes at a scale sufficient to base a decision on their acceptability, as judged by the important criteria of cost, environmental impact, and proliferation resistance. Considerable technical benefits could be gained from the experiences of previous R&D programs in the U.S. and in various foreign countries involved in similar technologies. Current U.S. policy does not encourage the civilian use of plutonium.

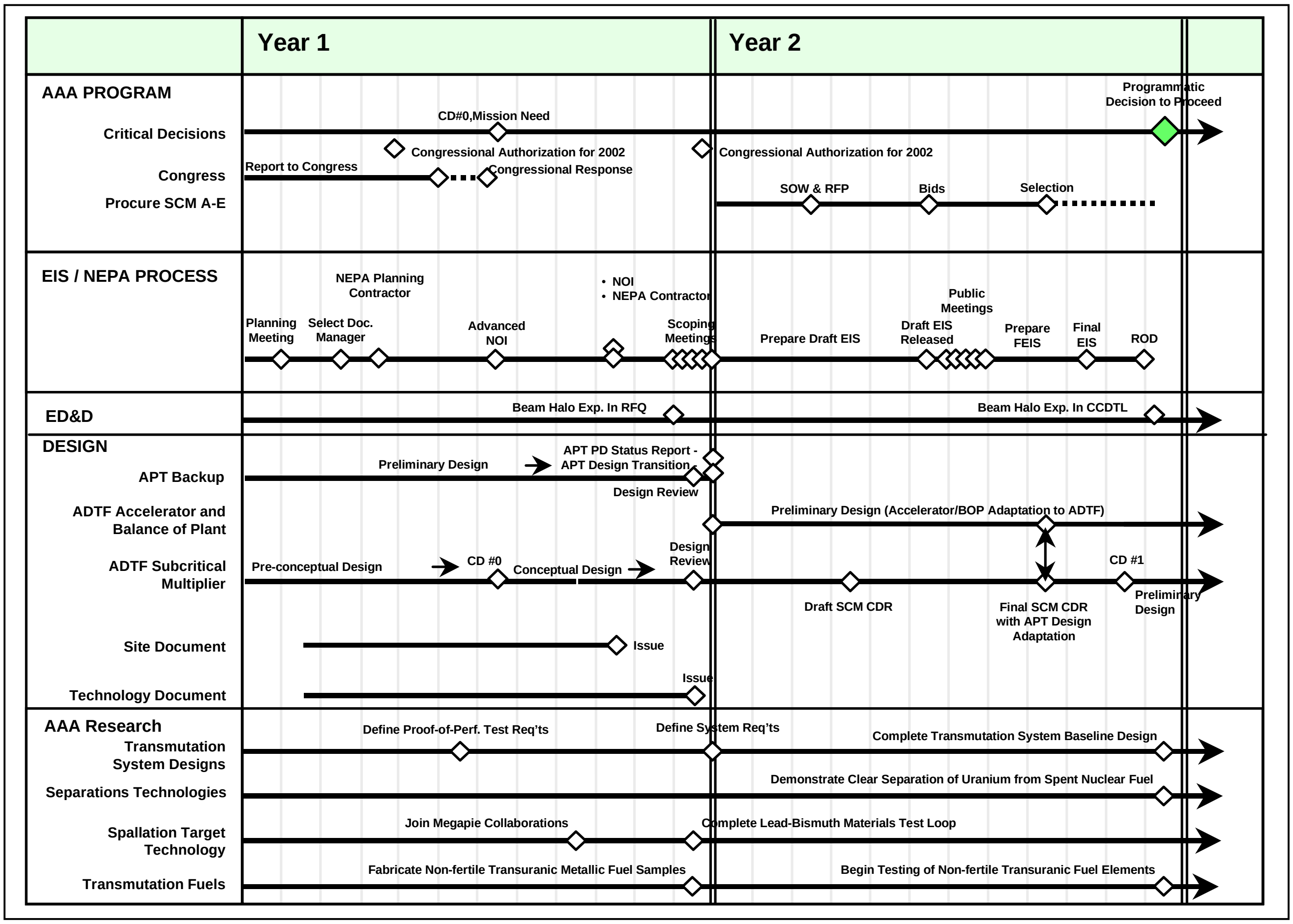
V. 10-Year AAA Program

In the first two years the Department would lay the groundwork for the AAA Program and define how the program would achieve its objectives. By the end of the second year, the AAA program would develop the scope, cost, environmental, and schedule data necessary to fully define the 10-year program and support a management decision regarding whether to proceed with the program.

The Initial Two Year Period

During the initial two-year period, conceptual design of the ADTF could be completed in close coordination with ongoing transmutation R&D activities to ensure technical requirements for that aspect of the program are met. From a design perspective, the ADTF has two distinct elements: 1) a proton accelerator and the associated 'balance of plant', or support facilities; and 2) the sub-critical multiplier. The accelerator and balance of plant would be based on an Accelerator Production of Tritium design, which has completed conceptual design and a majority of preliminary design. The sub-critical multiplier could enter conceptual design in the first year. The two designs would continue during the two-year period. By the end of the second year, the adaptation of APT accelerator design to the ADTF mission, as well as the conceptual design of the sub-critical multiplier could be completed. The results of these efforts would be documented in the ADTF Conceptual Design Report and would represent the preliminary integrated baseline for the facility. Assuming adequate resources and further project planning, the more advanced accelerator design would allow its final design to begin in the third year to support a construction start before the end of the fourth year. AAA Program technology development will parallel the ADTF design efforts during the period. Major activities would support ADTF development in technology areas such as accelerator and neutron spallation targets and provide additional data to support a decision on whether to proceed with the program at the end of the second year. Activities would include the definition of requirements for ADTF proof-of-performance demonstration of integrated transmutation systems, the development and testing of individual transmutation technologies (*e.g.*, non-fertile fuels), environmental, proliferation risk and economics assessments, and a separations process demonstration.

Prior to the inception of the AAA program, the APT program had planned to complete preliminary design of the APT and some elements of detailed design before terminating the program and archiving the design as a backup technology. An Engineering Development and Demonstration (ED&D) program was also to be completed. These activities would confirm the tritium production backup capability and bring design and R&D to an appropriate stopping point for the APT program. With initiation of the AAA program and funding reductions due to program budget ceilings, the point to which APT design and ED&D activities should be carried must be redefined consistent with the plan for design and, if approved, development of the ADTF. This is because the design of the facility, including balance of plant systems will, given



the potential new missions for the AAA program, be different from that of the APT. As a result, most of the preliminary design of the APT will be completed by the end of FY 01 and most of the ED&D activities originally planned will be conducted by the end of FY 2002. The APT activities to be completed are those necessary to establish the viability of accelerator production of tritium as a backup technology. Those activities would be leveraged to inform the design and, if approved, development of the ADTF, a cornerstone of the AAA program.

While design and R&D activities are under way, required National Environmental Protection Act (NEPA) actions would also be completed. A program Environmental Impact Statement (EIS) would be prepared leading to a record of decision on whether to proceed with the rest of the program and, if so, the location of the ADTF facility (site to be determined as part of the NEPA process). The program would perform analyses leading to a Preliminary Safety Analysis Report (PSAR). Finally, the AAA Program would perform and support independent and external reviews, independent cost estimates, and facilitate management reviews required prior to any Department management decision as to whether to proceed with a major program.

In the waste transmutation technology area, separations technology would be demonstrated in a radioactive environment that can separate uranium from spent fuel to such purity as to qualify it for low-level waste disposal. Fabrication processes would be developed and tested for producing non-fertile (*i.e*., avoiding production of additional transuranic waste) transmutation fuels containing the problem transuranics. The transmutation technology development would also include evaluation of multi-tier strategies using combinations of reactors and accelerator-driven systems**.**

'Two-Tier System'

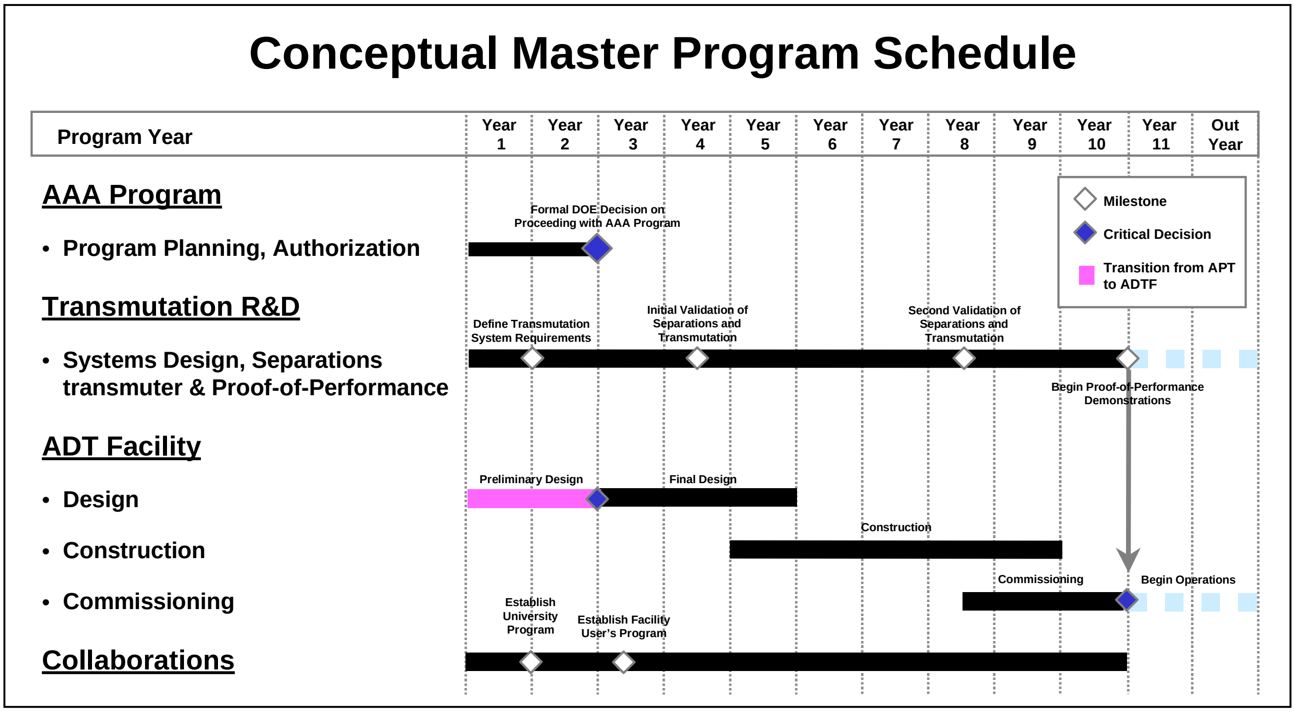
An approach to transmutation using thermal reactor technology (existing light water and/or gas cooled) to transmute plutonium and technetium first, and then an accelerator driven system to transmute minor actinides and iodine. Potential advantages include 1) improvement in economics, 2) reduced size and number of accelerator driven systems, and 3) early deployment of transmutation systems.

By the end of the second year the AAA program would have produced all of the data necessary to more completely define the entire 10-year program. The Two Year Program Schedule above displays the five major areas of activity during the two-year period, and the major efforts and milestones within those activities. All activities are planned to support a "Programmatic Decision to Proceed" at the end of the second year. To accomplish this goal would require appropriated funding for the first year of an AAA Program of about $70 million and in the range of $110 to $130 million for the second year.

10 Year Program

Detailed costs and schedules for the entire 10-year AAA Program can not be completed until the completion of an initial two-year conceptual design activity. However sufficient data exists today to allow a meaningful summary of major elements of the 10-year program.
Assuming a decision to proceed, in this period, the AAA program would focus on development of the new Accelerator-Driven Test Facility in parallel with transmutation research and development. The four major elements of the 10- year program are shown in the Conceptual Master Program Schedule below, with their key milestones. Transmutation R&D would continue, advancing technical readiness to the point where integrated testing using the ADTF would be appropriate.

Key tests along this development pathway would demonstrate successful performance of transmutation technology concepts and systems. Success of the overall program would hinge on making efficient use and coordination of national and international facilities to achieve timely, cost effective results. Major R&D efforts would be directed at the following technology areas: ADTF system performance requirements, sub-critical multiplier design, target/blanket coupling, separation processes, associated fuel and materials performance, waste forms and management. Final design of the accelerator and balance of plant would begin in the latter part of the second, or early in the third year of the program, with construction to begin in program year four, and completed in program year nine. Preliminary design of the sub-critical multiplier would begin in the third year of the program and final design in the fourth year, with construction start in year



six, and completion in year nine. Commissioning of the facility would begin in year eight. Operation of the new ADTF facility would begin late in the tenth year, with the transmutation proof-of-performance demonstration. Integrated safety management would be carried on in the 10-year period, as would a proactive university program, and international collaboration.

The Department estimates that in the range of $140 to $170 million would be required in the third year of a full AAA Program to complete required activities. The approximate cost for the entire 10-year AAA Program is estimated at $2.3 billion in FY 2001 dollars, including the construction of an ADTF and all relevant program research. This cost target is based on data from existing APT accelerator and balance of plant designs, pre-conceptual cost ranges for the sub-critical multiplier, and initial estimates of a 10-year supporting research and development program. Costs and funding profiles based on conceptual design will be available next year.

The program has adopted, with some adaptation, the APT project control systems. This provides the new program with a mature program control system including work packaging and accounting systems, change control, quality assurance processes, integrated safety management and formalized design review, reporting and financial management controls. APT project control systems have been examined, and been given positive reviews from various DOE, GAO, and external independent review groups.

International Cooperation

All countries that have deployed a significant nuclear power infrastructure over the past decades need to establish a solution to the nuclear waste issue. While some have opted for solutions limited to geologic repositories, others have started R&D programs on nuclear waste partitioning and transmutation and development of accelerator-driven facilities. Of these countries, France and Japan have the largest programs today, but other countries such as Germany and the Republic of Korea also have significant programs. These programs develop technologies in the areas of nuclear fuels, reactor concepts, and processing techniques, and have made small scale and large-scale demonstration of these technologies.

Collaborations with these countries through exchange of results would provide the U.S. with a strong technical basis to choose between indigenous and foreign technologies, and would economize U.S. resources and accelerate the outcome of the AAA program. Collaboration based on shared studies or experiments would help develop new technologies at a faster rate, and would enrich the U.S. knowledge base. These international programs were started in the early to mid 1990s and have not yet reached fruition. Nevertheless, they have already accumulated a large amount of scientific and technical data in physics, materials, and target design. It would be very beneficial for the U.S. to work with existing programs and join on-going experiments/studies.

Furthermore, this nascent area is ideal for launching cost or resource-shared international projects, where the combination of resources, talent, and expertise will result in more efficient programs and in the building of stronger international consensus in key technical aspects. Effective international collaboration can be envisioned for developing, building, and operating the ADTF. Further collaborations would be possible if ADTF becomes the premier international testing ground for transmutation technologies and nuclear R&D.

VII. Summary

If fully implemented, and assuming adequate resources and further project planning, the AAA program could develop and demonstrate advanced technologies directly applicable to solution paths for key domestic and international nuclear issues. If a decision were made to pursue a long term program, it could address the following objectives:

1. Construction of a first-of-a-kind nuclear engineering research facility with user access to advance nuclear science for energy and national security missions;
2. Demonstration of new, potentially improved alternatives to address the long-term management of used nuclear fuel;
3. Launching a strengthened academic nuclear infrastructure that educates new scientists and engineers for both energy and national security; and
4. Provide capability to augment radioisotope production, and provide a more robust tritium backup capability than originally envisioned.

This AAA Program document has defined a long term plan with an initial two-year definition period. During that two-year period, the Department would obtain sufficient information to support a management decision as to whether to proceed with an eight year activity to develop, design, and construct an ADTF. A broad national team of program, laboratory, and industry participants would execute the program, with independent oversight.

Note that this document has been prepared and written so that it is responsive to the direction in Conference Report 106-988, for the FY 2001 Energy and Water Appropriations Act. It makes no attempt to establish AAA as a priority among the several technologies that might benefit the future of nuclear power. Should the Department proceed with a program to develop AAA, the actual activities and schedule would depend on future funding.